

SIMULATION OF MICRO HYDRO POWER BASED ON RIVER CONFIGURATION AT RIVER  
UPSTREAM

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Thesis submitted in fulfillment of  
the requirements for the award of the degree of  
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering  
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

## ABSTRACT

Micro hydro power is a reliable form of energy. Pelton and Turgo turbine are examples of turbine that can be applied to install Micro Hydro Power. The purpose of this paper is to determine the performance and efficiency of Micro Hydro Power at Panching Waterfall, to simulate the flow of upstream river configuration and to determine the suitable turbine to be installed at high head river. Small scale hydro power can be develop in rural areas for clean electrification. The velocity and flow rate of the waterfall is determined and applied to the analysis to identify the suitable turbine to be used. To obtain the results, simulation using ANSYS CFX is done. The solver can determine the output velocity and torque of the flow through the respective cup, and then theoretical results are determined using calculations. The efficiency of Pelton is 0.965 while Turgo is 0.969. The value of torque is determined from the simulation results. The value is 9.25 N.m for Pelton and 7.41 N.m for Turgo. The results are then compared with theoretical results which the value for Pelton is 1.4 N.m and 1.316 for Turgo. From these results, the power output is calculated and the values are 1487.5 and 1483.5 for Pelton and Turgo respectively. These results clearly show that Pelton Turbine is suitable for high head Micro Hydro Power. On the other hand, simulation results also shows that Pelton has higher power output than Turgo where the values are 1476 watt and 1465.5 watt respectively.

## ABSTRAK

Kuasa mikro hydro adalah satu bentuk tenaga yang boleh diaplikasikan. Pelton dan Turgo turbin adalah contoh turbin yang boleh digunakan untuk kuasa mikro hidro. Laporan ini adalah untuk menentukan prestasi dan kecekapan kuasa mikro hidro di Air Terjun Panching, untuk mensimulasikan aliran konfigurasi hulu sungai dan untuk menentukan turbin yang sesuai untuk dipasang di sungai beraliran tinggi. Kuasa hidro Yyang kecil boleh dibangunkan di kawasan luar bandar bagi bekalan elektrik bersih. Halaju dan kadar aliran air terjun ditentukan dan digunakan untuk analisis untuk mengenal pasti turbin yang sesuai untuk digunakan. Simulasi menggunakan ANSYS CFX digunakan untuk mendapatkan data dan maklumat bagi aliran air . Penyelesai boleh menentukan kelajuan output dan tork aliran melalui cawan masing-masing, dan kemudian keputusan teori yang menentukan menggunakan pengiraan. Kecekapan Pelton ialah 0.965 manakala Turgo adalah 0,969. Nilai tork adalah menentukan dari resuts simulasi. Nilai adalah 9.25 Nm untuk Pelton dan 7.41 Nm untuk Turgo. Keputusan ini kemudiannya dibandingkan dengan keputusan teori yang mana nilai untuk Pelton ialah 1.4 Nm dan 1,316 untuk Turgo. Daripada keputusan ini, output kuasa dikira dan nilai masing-masing dan 1487,5 1483,5 untuk Pelton dan Turgo. Keputusan ini jelas menunjukkan bahawa Pelton turbin sesuai untuk kepala tinggi Micro Hydro Power. Keputusan ini juga selari dengan simulasi yang dilakukan dimana Pelton turbine Lebih tinggi daripada Turgo.

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**LIST OF SYMBOLS**

$\omega$	Tangential Component
T	Torque
P	Power
k	Velocity Coefficient
$v_1$	Velocity at Inlet
U	Bucket Velocity
$\eta$	Efficiency
r	Velocity Relative to Bucket
$\dot{m}$	Mass Flow Rate

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 PROJECT BACKGROUND**

Hydro power produces electricity using natural flow of water. This is considered the most cost effective energy technology for rural electrification in potential areas. Micro hydro power is developing around the country in producing clean electrification. Performance of micro hydro power depends on the site more on the cost.

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. Although there are several ways to harness the moving water to produce energy, run-of-the-river systems, which do not require large storage reservoirs, are often used for micro hydropower systems. Turbines are commonly used today to power micro hydropower systems. The moving water strikes the turbine blades, much like a waterwheel, to spin a shaft. But turbines are more compact in relation to their energy output than waterwheels. They also have fewer gears and require less material for construction.

Micro hydro power generally produces up to 100kW of electricity. These amounts of electricity can provide electricity in an isolated home or small community. This application is suitable to be implemented in rural areas. In Malaysia, there are many locations that have potential for micro hydro power.

Geographical factors are important for hydropower. The higher head of a stream may produce more power. Sites with higher head are most desirable because they need less water, smaller pipe, fewer nozzles, and cost less to install, and fare better in low water years. The main obstacle of micro hydro power is costs. Many researched had been done to determine the higher performance of turbine with lower operating and maintenance cost.

## **1.2 PROBLEM STATEMENTS**

Geographical factors play an important role in Micro Hydro Power Plant (MHPP). The height (head) of river, velocity of flow, sediment discharge, and rainfall and topology data differs in every place. These factors may affect the performance and efficiency of Micro Hydro Power. In rural areas such as places that are remote from other energy sources has very limited facility of having electricity for home users and other purpose. However different types of Micro Hydro Power differ in performance and efficiency. The effectiveness of Micro Hydro Power is affected by the flow of water.

## **1.3 RESEARCH OBJECTIVES**

- 1.3.1 To simulate the flow of upstream river for different Micro Hydro Power
- 1.3.2 To determine the performance and efficiency of Micro Hydro Power
- 1.3.3 To determine suitable Micro Hydro turbine for high head flow

## **1.4 PROJECT SCOPES**

- 1.4.1 The scope involve in this project focus on the upstream river configuration where the velocity, pressure and topology data is to be determined.
- 1.4.2 Simulation is conducted using ANSYS based on the data colle suitable Micro Hydro Power with higher performance.
- 1.4.3 From the results obtained, suitable MHP is determined to be used upstream river of higher head.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

In this chapter, information about hydropower is discussed. The sources of the review are extracted from journals, articles, reference books and internet. The purpose of this section is to provide additional information and relevant facts based on past researches which related to this project.

#### **2.2 ADVANTAGES OF MICRO HYDROPOWER**

Micro hydro power is hydroelectric power that typically produces 100kw electricity using natural flow of water. Small scale hydro power is cost effective and very reliable in producing clean electricity generation. A stream or river is used to generate electricity. Hydropower produces continuous supply from the flow of river. It is proven that micro hydro power is more economical than solar and wind power. There are many advantages of small hydropower that are going to be mention in the following paragraph.

According to research made by The British Hydropower Association, small hydropower has efficiency of 70-90%, so far the best compared to wind and solar power.

Higher efficiency will improve the performance of electricity generation. The research also proved that high capacity factor of micro hydro power (typically >50%), compared with 10% for solar and 30% for wind. Furthermore, small hydro has high predictability depends on the rainfall patterns. The flow and velocity of rivers changes slowly from day to day. These slow rate changes make the output of the hydro power changes gradually.

Small hydropower is a long lasting and robust technology. The system can be used as long as 50 years or sometimes more. Small hydro power also always follows the demand, during winter the output is maximum. This is a good correlation with demand. Small hydropower is environmental friendly where it does not affect the natural ecosystem. No reservoir required for micro hydro because it based on run-of-river system.

Small hydropower systems allow achieving self-sufficiency by using the best as possible the insufficient natural resource such as water, as a decentralized and low-cost of energy production. Hydropower is the most important energy source in what concerns no carbon dioxide, sulphur dioxide, nitrous oxides or any other type of air emissions and no solid or liquid wastes production. This system produces a cleaner energy system. It also saves the consumption of fossil, fuel and firewood (Ramos, H. et al).

## **2.3 PARAMETERS OF MICRO HYDRO POWER**

### **2.3.1 Head**

Head of flow is the vertical fall of water flow from higher to lower level due to potential energy. For example river passes a waterfall. Head is an important parameter of hydropower. The head affect the flow rate of the flow. Head of flow can be determined by measuring the flow from the highest point to the lowest water drop as shown in figure 2.1. The unit of head is in meter (m). It is generally better to have more head than more flow (British Hydropower Association).



**Figure 2.1:** Head of Flow

Source: Panching Waterfall

Gross Head ( $H$ ) is defined as the maximum level that is available for the vertical fall of water. The actual head seen by a turbine will be slightly less than the gross head. This is due to losses incurred when transferring in and out of the hydropower.

### **2.3.2 Flow Rate**

Flow is the quantity of water moving past a given point over a set time period (expressed as volume in gallons per minute (gpm) or cubic meters per second ( $m^3/s$ )). More water falling through the turbine will produce more power. The amount of water available depends on the volume of water at the source. Power is also ‘directly proportional’ to river flow, or flow volume. The flow rate is the product of volume and area (A.Zubaidi, 2010).

### 2.3.3 Power and energy

The amount of power available from a micro hydro generator system is directly related to the flow rate, head and the force of gravity. Once we have determined the usable flow rate (the amount of flow we can divert for power generation) and the available head for our particular site, we can calculate the amount of electrical power we can expect to generate (Zubaidi.A, 2010). Power is calculated using the following equation:

$$P = \rho g H Q \quad (2.2)$$

P= Power

$\rho$ =density of water

g= gravitational constant (9.81 m<sup>2</sup>/s)

H=head of flow

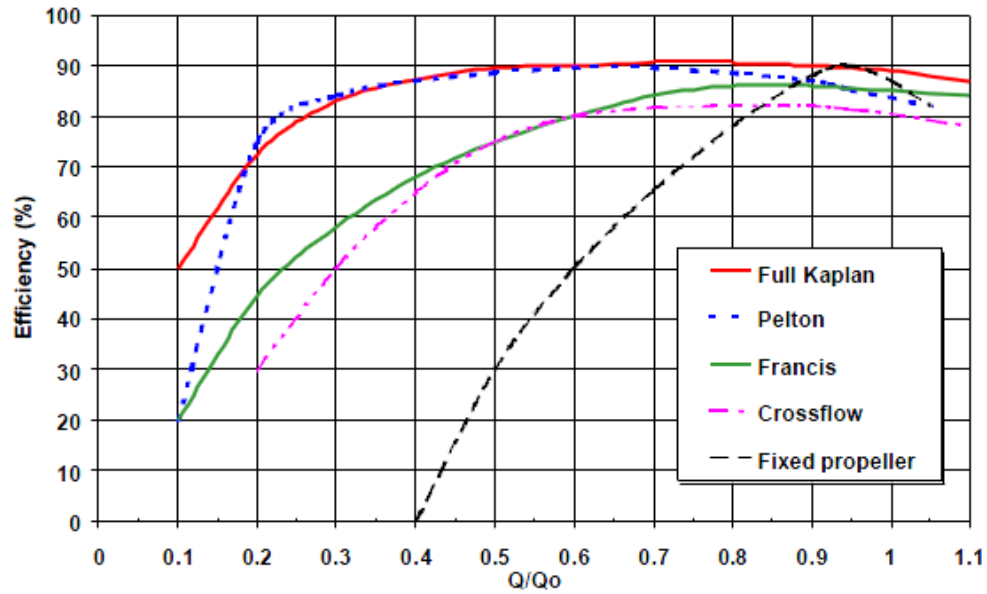
Q= Flow rate

## 2.4 TURBINE EFFICIENCY

Efficiency is defined as a level of performance that describes a process that uses the lowest amount of inputs to create the greatest amount of outputs. For hydropower, the efficiency and performance of the plant mainly depends on the types of turbine used. Turbine selection is depending on the scale of hydropower and the location to install the turbine. Efficiency is affected by the Head (H), flow rate (Q), density of water ( $\rho$ ) and gravitational constant.

Comparison between few turbines is made to determine the higher performance turbine. An important point to note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Crossflow and Francis turbines falls away more sharply if run at below half their normal flow. Most fixed-pitch propeller turbines perform poorly except above 80% of full flow (British Hydropower Association, 2005).





**Figure 2.2:** Turbine efficiency

Source: British Hydropower Association (2005)

The efficiency of turbine can be calculated using the following equation

$$P = \eta \times \rho \times g \times H_{\text{net}} \times Q \quad (2.3)$$

$\eta$  = efficiency of turbine

$\rho$  = density of water [kg/m<sup>3</sup>]

$g$  = gravitational constant [m/s<sup>2</sup>]

$H_{\text{net}}$  = net head [m]

$Q$  = volumetric flow rate [m<sup>3</sup>/s]

**Table 2.1:** Turbine Efficiency

<b>Turbine</b>	<b>Efficiency</b>
Pelton	0.90
Banki-Mitchell	0.87
Turgo	0.85
Francis	0.90
Kaplan	0.90

Source: Johnson.V (2008)

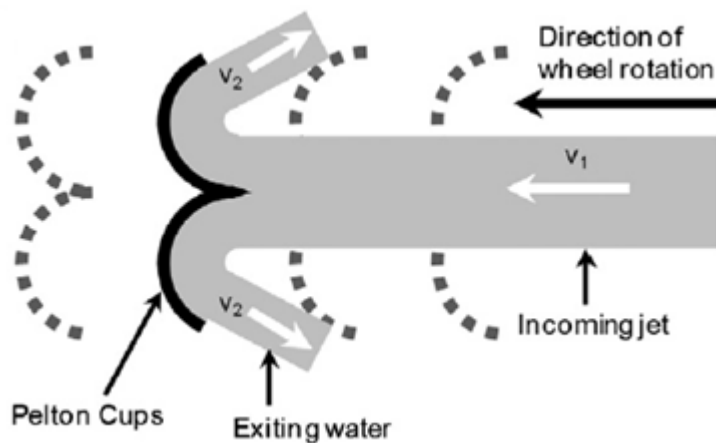
## **2.5 TURBINE SELECTION FOR MICRO HYDRO POWER**

### **2.5.1 Pelton Turbine Designation Properties**

The Pelton turbine consists of a wheel with a series of split buckets set around its rim a high-velocity jet of water is directed tangentially at the wheel. The jet hits each bucket and is split into half, so that each halves is turned and directed back almost through 180°.Almost all the energy of the water goes into propelling the bucket and the directed water falls into a discharge channel below (O Paish, 2002).

There are many research proved that Pelton turbine is suitable to be apply in Micro Hydro Power over a relatively wide range head and flow conditions when compared to other turbine categories and is suitable for many medium and high head sites. There are many design of Pelton turbine in order to suits the condition of the flow. For micro hydro power upstream configuration, Pelton turbine is suitable to be used because of its

characteristics. Pelton runners are subject to a combination of stresses caused by centrifugal force and cyclic loads. The centrifugal force is induced by the fast rotating body and is related to the runner speed and mass (G.Gilkes et al, 2003)



**Figure 2.3:** Pelton Turbine Cup

Source: S.J. Williamson (2012)

### 2.5.2 EFG Interlocking Runner Buckets

The method is based on a forging technique to produce buckets that include a patented interlocking clamping system, which link together the buckets to form the runner. Individual buckets can then be individually removed for repair or maintenance. After forging, the buckets are individually CNC machined to improve the surface finish and complete the required tolerances (G.Gilkes et al, 2003).



**Figure 2.4:** EFG Interlocking Runner Buckets

Source: G.Gilkes et al (2003)

For a Pelton runner, there are always be losses due to many surrounding effect. So the efficiency,  $\eta$  of turbine is set to 0.9. The diameter of nozzle can be determined from the following equation:

$$C = \sqrt{2gH} \quad (2.4)$$

$$d_s = \sqrt{\frac{4Q}{Z\pi C}} \quad (2.5)$$

where:

Q= Flow rate

z= Number of nozzles

H= head

The diameter of runner can be determined from the following

$$D = 10.d_s \quad H_n < 500 \text{ m}$$

$$D = 15.d_s \quad H_n = 1300 \text{ m}$$

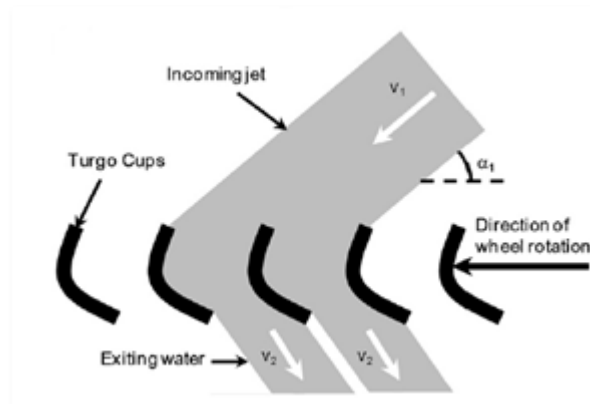
Source: Design of Pelton Turbine Powerpoint Slides

The theoretical maximum power achievable by a Pelton turbine occurs when the wheel rotates at the following equation when the bucket moves at half the speed of the water jet (Yunus A.C,2006, pg 811).

$$W = \frac{V_J}{2r} \quad (2.6)$$

### 2.5.3 Turgo Turbine Design Consideration

For high head micro hydro power, impulse turbine is more preferred to be used rather than reaction turbine which is suitable for low head flow. According to S.J. Williamson, Turgo turbines were invented and patented in 1920 by Gilbert Gilkes Ltd (as cited in Gibson AH, 1948). The author also mentioned that, the differences of Turgo and Pelton turbines are the angle of incoming water jet is different. In Turgo turbines the jet enters and exits the wheel plane at an acute angle whereas in Pelton turbines the jet remains in the same wheel plane. Therefore, the water in a Turgo turbine exits from the bottom of the wheel and does not interfere with the incoming jet.



**Figure 2.6:** Torque generation mechanism of Turgo turbine

Source: S.J. Williamson (2012)

A Turgo turbine requires a penstock, nozzle and turbine wheel also known as disc. The following assumptions are made to act as a controlled for the experiment. All of the flow impacts with the cup in the parallel section. There is no radial flow within the cup, the incoming jet is not impinged by the exiting water or by the incoming cup, and there are no losses due to non-ideal entry conditions. Frictional velocity losses inside the cup are 5% (S.J. Williamson, 2012).

The velocity  $v_1$  of the flow falling through a head  $H$  leaving the nozzle can be calculated by

$$V_1 = k\sqrt{2gH} \quad (2.7)$$

and the continuity equation is

$$Q = \frac{V_1(\Pi D_j^2)}{4} \quad (2.8)$$

where:

$k$  = loss factor from the nozzle

$g$  = gravitational force

$H$  = head

$Q$  = flow rate

$D_j$  = jet diameter

Therefore for a constant jet diameter, as the head increases the flow rate also increases. As the jet impacts the cup, it splits into two components and exits through the top and bottom of the cup (S.J. Williamson, 2012). This concepts increase the efficiency of the turbine.

Turgo turbine can handle significantly higher water flow rates. Turgo turbine is a low cost turbine where the runner is less expensive compared to Pelton. Furthermore, it doesn't need an airtight housing like the Francis. Moreover, it has higher specific speed

and can handle a greater flow than the same diameter Pelton wheel, leading to reduced generator and installation cost (Bryan R.C, 2012).



**Figure 2.7:** 3D model of Turgo cups attached to wheel to form turbine disc

Source: S.J. Williamson (2012)

## **2.6 MICRO HYDRO POWER POTENTIAL IN RURAL AREAS**

Hydropower, large and small, is by far the most important of the 'renewable' for electrical power production. World Hydropower Atlas 2000, published by the International Journal of Hydropower and Dams, reported that the world's technically feasible hydro potential is estimated at 14370TWh/year, which equates to 100 per cent of today's global electricity demand (O Paish, 2002).

Many rural areas in Malaysia have no access to electricity, which may lead to lack of socio economic development. Majority of electrical supply in Malaysia is produces by Tenaga Nasional Berhad (TNB). The total energy supplied for electricity generation is constituted by fossil fuel. Burning of fossil fuel will not last forever and it is damaging the environment and affecting the climate through the emission of greenhouse gases. Micro hydro power is the best solution to overcome this problem as it does not require dams and weirs. Furthermore, the impact to environment is very small.

Water is the only force running the plant and no fuel like diesel is needed as input. In areas that have flowing water such as river, waterfall and stream, there are potential of having micro hydro power in the area (Sundqvist,E et al, 2006). In Malaysia, the weather and geographical factors must be examined first before installing micro hydro power in that certain location.

The feasibility study of a hydroelectric plant, even if small, needs information on the available water resources in order to assess the potential energy production of the plant. The flow duration curve of the stream is derived from the data published in the Italian Annals of hydrology (A. Renata, 2011).